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Photometric study of southern SU UMa-type dwarf novae and candidates – III: NSV 10934, MM Sco, AB Nor, CAL 86

Taichi Kato[1], Peter Nelson[2], Chris Stockdale[3], Berto Monard[4], Tom Richards[5], Rod Stubbings[6], Hitoshi Yamaoka[7], Bernard Heathcote[8], Roland Santallo[9]

[1] *Department of Astronomy, Faculty of Science, Kyoto University, Sakyo-ku, Kyoto 606-8502 Japan*
[2] *RMB 2493, Ellinbank 3820, Australia*
[3] *Hazelwood Observatory, RMB 4036 Matta Drive, Hazelwood South, Victoria 3840, Australia*
[4] *Bronberg Observatory, PO Box 11426, Tiegerpoort 0056, South Africa*
[5] *Woodridge Observatory, 8 Diosma Rd, Eltham, Vic 3095, Australia*
[6] *19 Greenland Drive, Drouin 3818, Victoria, Australia*
[7] *Faculty of Science, Kyushu University, Fukuoka 810-8560, Japan*
[8] *Tardis Astronomical Observatory, Mia Mia, Victoria, Australia*
[9] *Southern Stars Observatory, Po Box 60972, 98702 FAAA TAHITI, French Polynesia*

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ABSTRACT

We photometrically observed four southern dwarf novae in outburst (NSV 10934, MM Sco, AB Nor and CAL 86). NSV 10934 was confirmed to be an SU UMa-type dwarf nova with a mean superhump period of 0.07478(1) d. This star also showed transient appearance of quasi-periodic oscillations (QPOs) during the final growing stage of the superhumps. Combined with the recent theoretical interpretation and with the rather unusual rapid terminal fading of normal outbursts, NSV 10934 may be a candidate intermediate polar showing SU UMa-type properties. The mean superhump periods of MM Sco and AB Nor were determined to be 0.06136(4) d and 0.08438(2) d, respectively. We suggest that AB Nor belongs to a rather rare class of long-period SU UMa-type dwarf novae with low mass-transfer rates. We also observed an outburst of the suspected SU UMa-type dwarf nova CAL 86. We identified this outburst as a normal outburst and determined the mean decline rate of 1.1 mag d^{-1}.

Key words: accretion: accretion disks — stars: cataclysmic — stars: dwarf novae — stars: individual (NSV 10934, MM Sco, AB Nor, CAL 86)

1 INTRODUCTION

Cataclysmic variables (CVs) are close binary systems consisting of a white dwarf and a red-dwarf secondary transferring matter via Roche-lobe overflow. SU UMa-type dwarf novae comprise an important subgroup of CVs, which is characterized by the presence of superoutbursts and superhumps. The superhumps and superoutbursts are now widely believed to be a result of the combination of two types of disk-instabilities (thermal and tidal instabilities), which have provided a laboratory to understand the basic astrophysical processes, such as the origin of viscosity and resonant actions on a fluid disk in close binaries (see a review by Osaki (1996); see also Ogilvie 2002 for recent theoretical development). We, the VSNET Collaboration (Kato et al. 2003d),[1] have been studying the properties of (mostly new) southern SU UMa-type dwarf novae, candidates, and related systems with a perspective described in Kato et al. (2003c). In this paper, we report on the detection of superhumps in three systems, and also report on photometric observations of an SU UMa-type candidate which underwent a likely normal outburst.

[1] http://www.kusastro.kyoto-u.ac.jp/vsnet/.

Table 1. Observers and Equipment.

Observer (Abbr.)	Telescope[a]	CCD	Software
Heathcote (H)	35.5-cm SCT	Audine	AIP4Win
Nelson (N)	32-cm reflector	ST-8E	AIP4Win
Monard (M)	30-cm SCT	ST-7E	AIP4Win
Richards (R)	18-cm refractor	ST-7E	AIP4Win
Santallo (Sa)	20-cm SCT	ST-7E	AIP4Win
Stockdale (St)	28-cm SCT	Meade 416XTE	MaxIm[b] AIP4Win

[a] SCT = Schmidt-Cassegrain telescope.
[b] Used for NSV 10934.

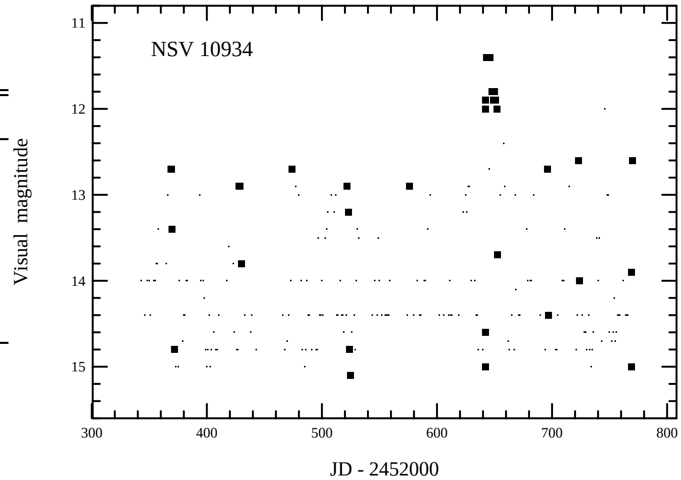


Figure 1. Long-term visual light curve of NSV 10934. In addition to short, normal outbursts recurring with time-scales of 40–60 d, there is a long, bright superoutburst around JD 2452643. The enlarged CCD light curve of this superoutburst is shown in Figure 2.

2 CCD OBSERVATION

The observers, equipment and reduction software are summarized in Table 1. All observers performed aperture photometry, and the magnitudes were determined relative to a nearby comparison star, which was confirmed to be constant during the observation by a comparison with a check star. The observations used unfiltered CCD systems having a response close to Kron-Cousins R_c band for outbursting dwarf novae. The errors of single measurements are typically less than 0.01–0.03 mag unless otherwise specified. The observers abbreviations will be used in "Obs" field in the later observing logs.

Barycentric corrections to the observed times were applied before the following analysis.

3 NSV 10934

3.1 Introduction

NSV 10934 was originally discovered as a large-amplitude suspected variable star of unknown classification. Kato et al. (2002a) noticed the identification with a bright ROSAT source (1RXS J184050.3−834305), and suggested that the object is a cataclysmic variable. Kato et al. (2002a) indeed detected multiple outbursts. These outbursts generally bore resemblance to dwarf nova outbursts, but are unusual in the rapid decline during the terminal stages of these outbursts. From these findings, Kato et al. (2002a) suggested that NSV 10934 may be an analogous object to the intermediate polar (IP), HT Cam, which shows brief dwarf nova-like outbursts (Ishioka et al. 2002; Kemp et al. 2002). Kato et al. (2002a) also predicted that the orbital period of NSV 10934 would be slightly longer than that of HT Cam (86 min), if NSV 10934 indeed turns out to be an HT Cam-like object.

Since then, NSV 10934 has been monitored by one of the authors (Rod Stubbings), and it has been established, by the end of 2002, that the object shows short outbursts, as described in Kato et al. (2002a), at rather regular intervals of 40–60 d. Following a call for observing campaign in 2002 December (vsnet-campaign-dn 3141[2]), the object went into a superoutburst, which will be described in the next subsection. A recent long-term visual light curve is shown in Figure 1.

3.2 2003 January Outburst

The outburst was first detected on 2003 January 2.480 UT at a visual magnitude of 15.0 by Rod Stubbings. On January 2.767 UT, the object was observed to further brighten to 11.9 mag (vsnet-alert 7601[3]). A time-resolved CCD photometric campaign started on the next night of this detection. The object was still rising in brightness. As described later, this outburst was confirmed to be a superoutburst by the detection of secure superhumps. The log of observation is summarized in Table 2.

Figure 2 shows the entire light curve of this superoutburst drawn from CCD observations. The CCD magnitudes (system close to R_c) are given relative to GSC 9523.351 (R_c ~11.8). The zero point is adjusted to the most comprehensive Peter Nelson's observations.

3.3 Superhumps

Figure 3 shows nightly light curves of NSV 10934 during the 2003 January superoutburst. The light curve on January 3 showed almost no feature of superhumps. On January 4, superhumps started to grow. The amplitudes of the superhumps reached a maximum at around January 5–6. We first determined the mean superhump period using Phase Dispersion Minimization (PDM: Stellingwerf 1978), after removing the linear decline trend during the plateau stage (January 5–13) of the superoutburst. The result is shown in Figure 4. The strongest signal at a frequency of 13.373(1) d^{-1} corresponds to the best superhump period of 0.07478(1) d. The selection of the correct alias has been confirmed by independent analyses of continuous nightly observations.

Figure 5 shows the mean superhump profile (of the plateau phase of the superoutburst), phase-averaged with the period of 0.07478 d. The rapid rise and slower decline are characteristic of SU UMa-type superhumps (Vogt 1980; Warner 1985).

[2] http://www.kusastro.kyoto-u.ac.jp/vsnet/Mail/campaign-dn3000/msg00141.html

[3] http://www.kusastro.kyoto-u.ac.jp/vsnet/Mail/alert7000/msg00601.html.

Table 2. Journal of the 2003 CCD photometry of NSV 10934.

2003 Date		Start–End[a]	Exp(s)	N	Obs
Jan.	3	52643.014–52643.159	15	192	St
	3	52643.271–52643.467	20	626	M
	4	52643.970–52644.131	15	276	St
	5	52644.958–52645.137	15	281	St
	5	52644.962–52645.080	15	334	N
	6	52645.944–52646.134	15	256	St
	6	52645.966–52646.185	10	685	N
	6	52645.978–52646.205	30	443	R
	8	52647.958–52648.010	20	130	N
	10	52649.942–52650.125	15	292	St
	10	52649.958–52650.241	40	492	R
	10	52649.985–52650.235	15	628	N
	11	52650.938–52651.125	15	214	St
	11	52650.963–52651.263	40	492	R
	12	52651.951–52652.123	15	335	St
	12	52651.989–52652.233	20	525	N
	12	52652.013–52652.246	40	400	R
	15	52654.992–52655.219	180	98	N

[a] BJD−2400000.

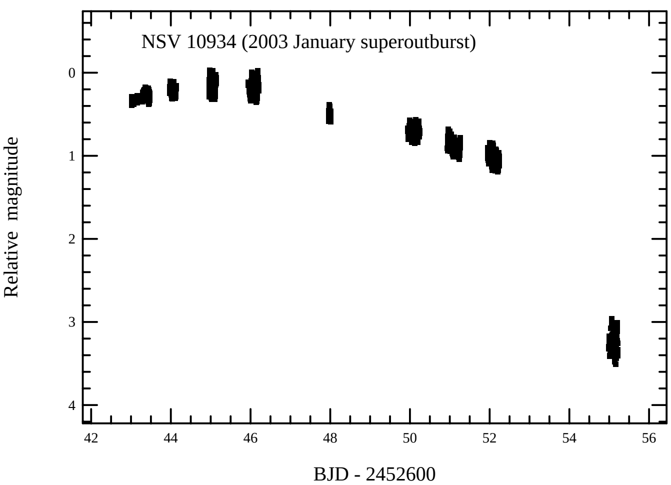


Figure 2. The 2003 January superoutburst of NSV 10934. The CCD magnitudes (close to R_c) are given relative to GSC 9523.351 (R_c ∼11.8).

3.4 Superhump period change

We extracted the maximum times of superhumps from the light curve by eye. The averaged times of a few to several points close to the maxima were used as representatives of the maximum times. Thanks to the high-precision data, the errors of the maximum times are usually less than ∼0.001 d. The resultant superhump maxima are given in Table 3. The values are given to 0.0001 d in order to avoid the loss of significant digits in a later analysis. The cycle count (E) is defined as the cycle number since BJD 2452643.9874. A linear regression to the observed superhump times gives the following ephemeris (the errors correspond to 1σ errors at $E = 48$):

$$\mathrm{BJD(maximum)} = 2452644.0033(16) + 0.074851(38)E. \quad (1)$$

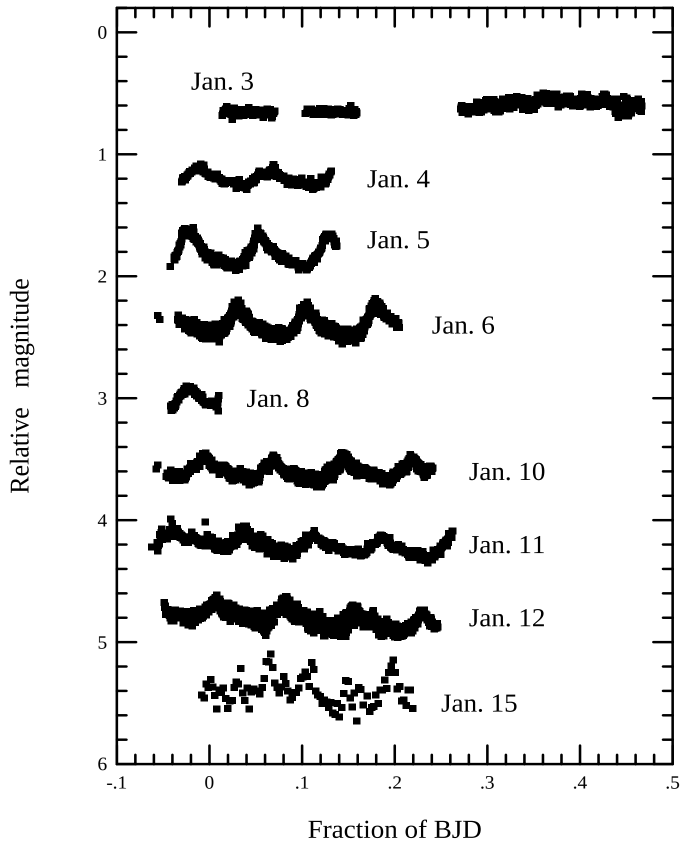


Figure 3. Nightly light curves of NSV 10934 during the 2003 January superoutburst. The light curve on January 3 showed almost no feature of superhumps. On January 4, superhumps started to grow. The amplitudes of the superhumps reached a maximum around January 5–6.

Figure 6 shows the $(O-C)$'s against the mean superhump period (0.074851 d) from a linear regression (equation 1). The diagram clearly shows the decrease in the superhump period throughout the superoutburst plateau. The superhump maxima during the plateau phase (13$\leq E \leq$110) is well expressed by a quadratic term corresponding to a period derivative of $\dot{P}/P = -10.2\pm1.0 \times 10^{-5}$. The earlier stage ($E$ <13) shows a large deviation from this quadratic fit, which is probably a result of the rapid evolution of superhumps at this stage. The observed decrease of the superhump period is one of the largest among known SU UMa-type dwarf novae (cf. Kato et al. 2003c).

3.5 Super-QPOs?

On January 4 (just after the initial growth time of the superhumps), there was an indication of quasi-periodic oscillations (QPOs) superimposed on superhumps (Figure 7). The lower panel of Figure 7 is to better illustrate the QPO signal, by subtracting the mean superhump profile by using a Fourier decomposition of the superhump profile from these data up to the fourth harmonics. Figure 8 shows the power spectrum of the QPOs. The strongest signal was found at a frequency of 65 d^{-1}, corresponding to a period of 0.015 d. No comparable QPOs were observed on preceding and following nights. This transient appearance of the QPO sig-

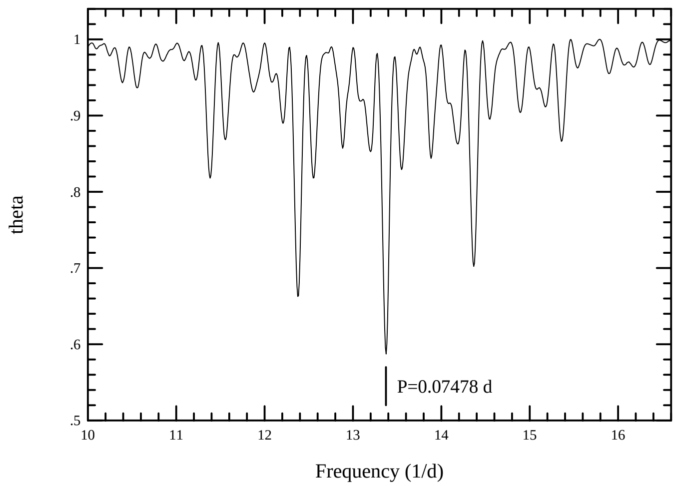


Figure 4. Period analysis of NSV 10934 (plateau stage: 2003 January 5–13). The strongest signal at a frequency of 13.373(1) d^{-1} corresponds to the best superhump period of 0.07478(1) d.

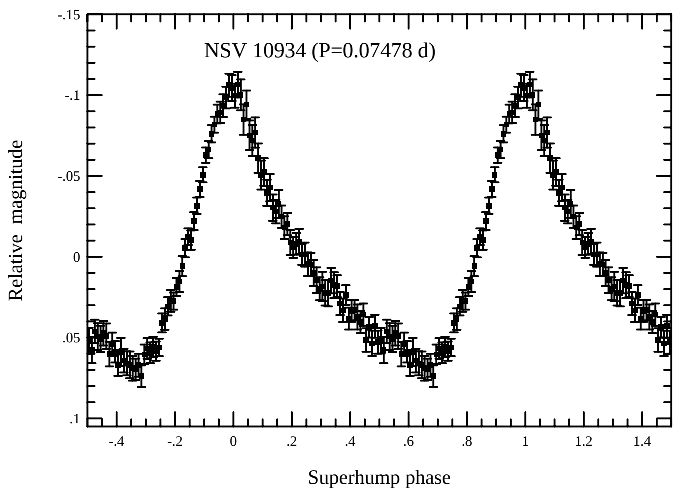


Figure 5. Mean superhump profile of NSV 10934.

Table 3. Times of superhump maxima of NSV 10934.

E^a	BJD−2400000	$O-C^b$
0	52643.9874	-0.0159
1	52644.0693	-0.0089
13	52644.9766	0.0002
14	52645.0537	0.0024
15	52645.1289	0.0028
27	52646.0301	0.0058
28	52646.1049	0.0057
29	52646.1791	0.0051
53	52647.9784	0.0080
80	52649.9951	0.0037
81	52650.0707	0.0045
82	52650.1470	0.0059
83	52650.2161	0.0002
94	52651.0398	0.0004
107	52652.0082	-0.0042
108	52652.0825	-0.0048
109	52652.1569	-0.0052
110	52652.2315	-0.0055

[a] Cycle count since BJD 2452643.9874.
[b] $O-C$ calculated against equation 1.

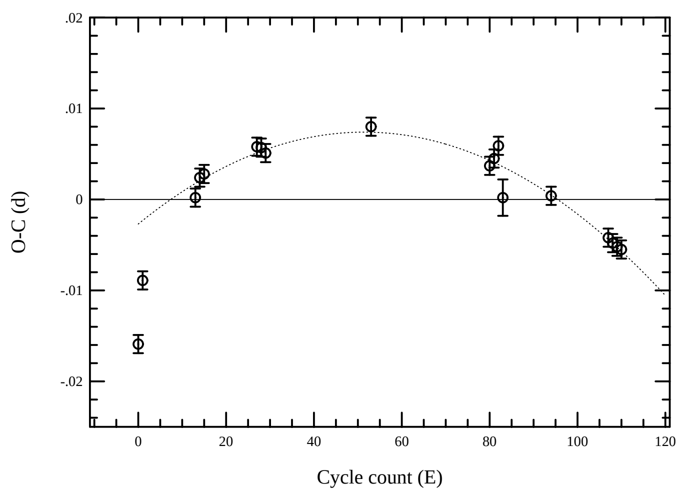


Figure 6. $O-C$ diagram of superhump maxima of NSV 10934. The error bars correspond to the upper limits of the errors except for $E=83$, which has a larger error 0.002 d. The parabolic fit for $13\leq E\leq 110$ is shown with a dotted line.

nal is very reminiscent of "super-QPOs" in some SU UMa-type dwarf novae, which only appear during the early stage of the superhump evolution (Kato et al. 1992; Kato 2002). Warner & Woudt (2002) suggested that these super-QPOs would be a result of interaction between the weak magnetism of the white dwarf and some kind of wave in the inner accretion disk. If this interpretation could apply to NSV 10934, the possible intermediate polar-type interpretation of this object (Kato et al. 2002a) would be consistent with the present finding.

3.6 NSV 10934 as an SU UMa-Type Dwarf Nova

Although the supercycle length of NSV 10934 has not yet been established, the intervals between normal outbursts (40–60 d) are typical values for an SU UMa-type dwarf nova in the intermediate activity class (Vogt 1993). The apparent lack of terminal brightening during the superoutburst plateau also fits the general properties of SU UMa-type dwarf nova with this superhump period (Kato et al. 2003b). However, the presence of terminal rapid declines during normal outbursts (Kato et al. 2002a) is rather unusual, because the contribution from quiescent luminosity usually works to slow down the decline rate near the terminal stage of such outbursts (e.g. van Paradijs et al. 1994). It may be that the inner accretion disk is truncated by the weak magnetic field of the white dwarf to produce such rapid terminal declines (e.g. Ishioka et al. 2002), while the field strength is not strong enough to moderate dwarf nova-type outburst properties (e.g. Angelini & Verbunt 1989). As stated in section 3.5, the supposed presence of a weak magnetic field would naturally explain the appearance of super-QPOs at the same time. A search for a coherent signal in X-ray, ultraviolet, and optical wavelengths is encouraged. The only other SU UMa-type dwarf nova which was proposed to be an IP is VZ Pyx (Remillard et al. 1994; Alvarez et al. 1995; Kato & Nogami

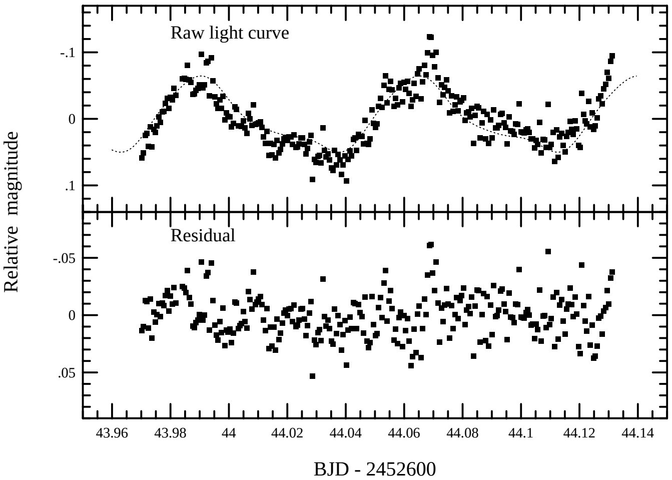


Figure 7. Enlarged light curve NSV 10934 on 2003 January 4. (Upper:) Raw data (the dotted line represents the best-fit superhump signal). (Lower:) Residual light curve subtracted for the best-fit mean superhump light curve. Quasi-periodic oscillations with periods ~0.015 d are present.

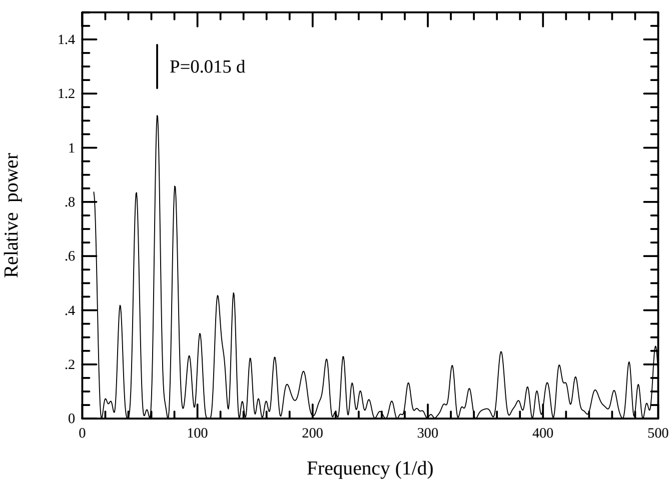


Figure 8. Power spectrum of the QPOs on 2003 January 4. The strongest signal is at a frequency of 65 d^{-1}, corresponding to a period of 0.015 d.

1997; Kiyota 1999). Although this object was originally proposed to be an IP, the modern observational evidence is rather against this classification (cf. Kato & Nogami 1997; Warner et al. 2003).[4]

[4] The well-known SU UMa-type dwarf nova SW UMa is also suspected to be an IP (Shafter et al. 1986; Robinson et al. 1987; Szkody et al. 1988; Rosen et al. 1994), although the outburst parameters of SW UMa are rather unusual among SU UMa-type dwarf novae (Shafter et al. 1987; Howell et al. 1995a,b). It is possible that this possible IP nature may be responsible for the most striking appearance of super-QPOs (Kato et al. 1992).

Table 4. Journal of the 2002 CCD photometry of MM Sco.

2002 Date		Start–End[a]	Exp(s)	N	Obs
Sept.	10	52528.221–52528.390	45	214	M
	11	52529.200–52529.436	45	327	M
	12	52529.715–52529.828	20	328	Sa

[a] BJD−2400000.

4 MM Sco

4.1 Introduction

MM Sco was discovered as a dwarf nova on Harvard plates (cf. Glasby 1970; Walker & Olmsted 1958). Petit (1956) suggested, from the apparently long outburst interval (≥500 d), that MM Sco may a similar object to UV Per, which is currently known as an SU UMa-type dwarf nova with long supercycles (Udalski & Pych 1992; Kato 1990; see also Kato et al. 2001b for a discussion on the relation to WZ Sge-type dwarf novae). This cycle length was adopted in Kukarkin et al. (1969). However, F. M. Bateson suggested that the mean outburst cycle length (~28 d) is much shorter than what has been believed, and observed maxima were fainter than the originally reported magnitude (see the description in Vogt (1983); this period was adopted in Kholopov et al. (1985); for a more recent reference, see Bateson et al. 1997). The reported outburst characteristics of MM Sco was thus rather controversial.[5]

4.2 2002 September Outburst

MM Sco has been monitored by the VSNET members since the outburst in 1997 (cf. vsnet-alert 946[6]) because of its apparently low frequency of outbursts, which is a rather commonly met signature of SU UMa-type dwarf novae.

The 2002 September outburst was detected by Rod Stubbings on 2002 September 5.428 UT at a visual magnitude of 14.0 (vsnet-outburst 4485[7]). The object further brightened to a magnitude of 13.4 next night, indicating that the present outburst may be a long, bright outburst. We carried out time-resolved CCD photometry upon this information. The log of observation is summarized in Table 4.

Figure 9 shows the nightly light curves of MM Sco. Superhumps were clearly visible on all nights; this confirms the SU UMa-type nature of MM Sco. Figure 10 shows the result of a period analysis using PDM applied to the entire data set after removing the nightly linear decline trends. The strongest signal at a frequency of 16.298(11) d^{-1} corresponds to the best superhump period of 0.06136(4) d.

Figure 11 shows the mean superhump profile phase-averaged with the period of 0.06136 d. The rapid rise and slower decline are characteristic of SU UMa-type superhumps. We did not attempt to determine a period derivative

[5] In a most recent publication, Mason & Howell (2003) listed MM Sco as a candidate SU UMa-type dwarf nova, though they reported that no superhumps have yet been observed.
[6] http://www.kusastro.kyoto-u.ac.jp/vsnet/Mail/vsnet-alert/msg00946.html.
[7] http://www.kusastro.kyoto-u.ac.jp/vsnet/Mail/outburst4000/msg00485.html.

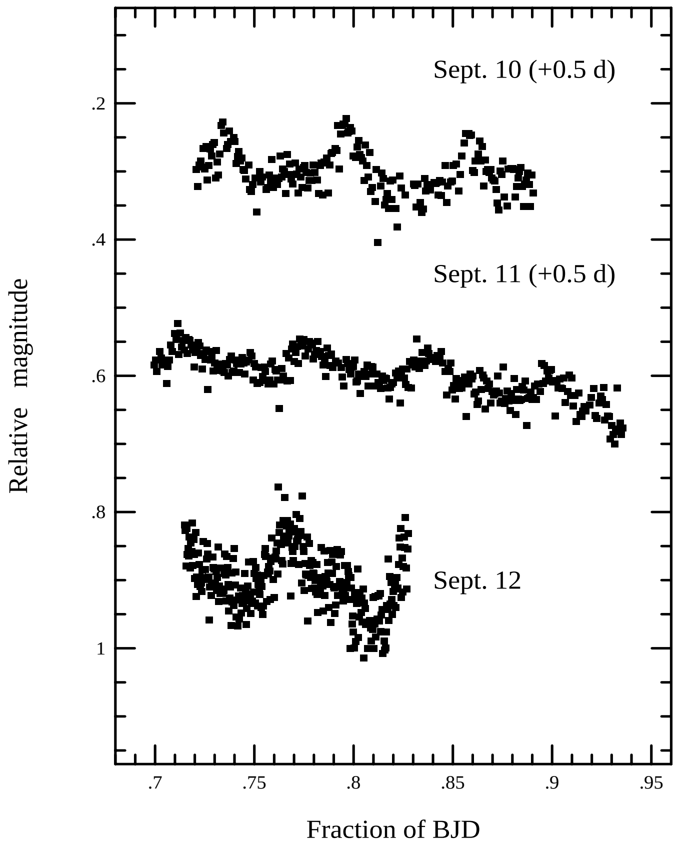


Figure 9. Nightly light curves of MM Sco. Superhumps were clearly visible on all nights.

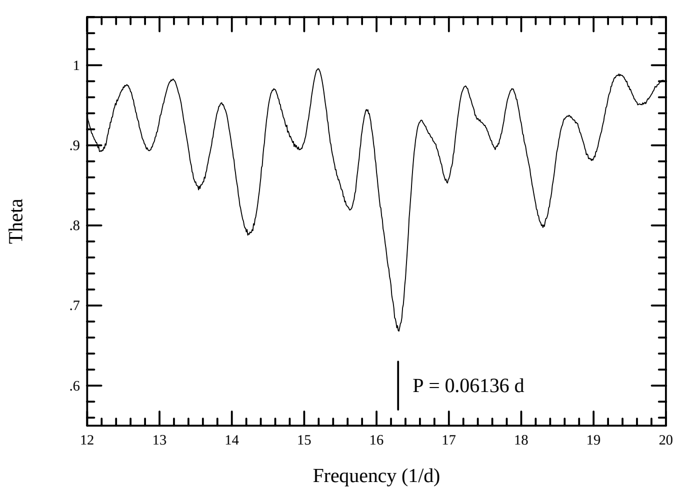


Figure 10. Period analysis of MM Sco. The strongest signal at a frequency of 16.298(11) d^{-1} corresponds to the best superhump period of 0.06136(4) d.

(e.g. Kato et al. 2003c,a) because of the short baseline of the observation. The less sharp appearance of the superhump maximum, compared to other fully grown superhumps of SU UMa-type dwarf novae (e.g. Harvey & Patterson (1995)), was probably because the observation started $\sim$5 d after the start of the superoutburst. The superhumps may have entered its decaying phase at the time of our observation. Further detailed observations of the full evolutionary course

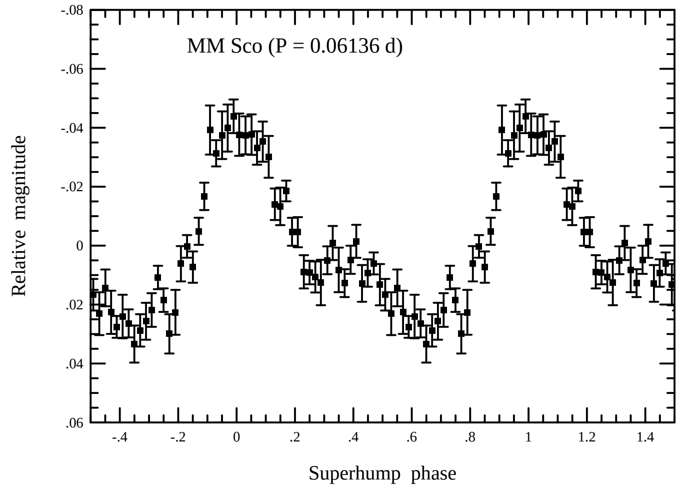


Figure 11. Mean superhump profile of MM Sco.

of the superhumps, as well as determination of the orbital period, are strongly encouraged to fully understand the behavior of superhumps in this system.

4.3 Astrometry and Quiescent Counterpart

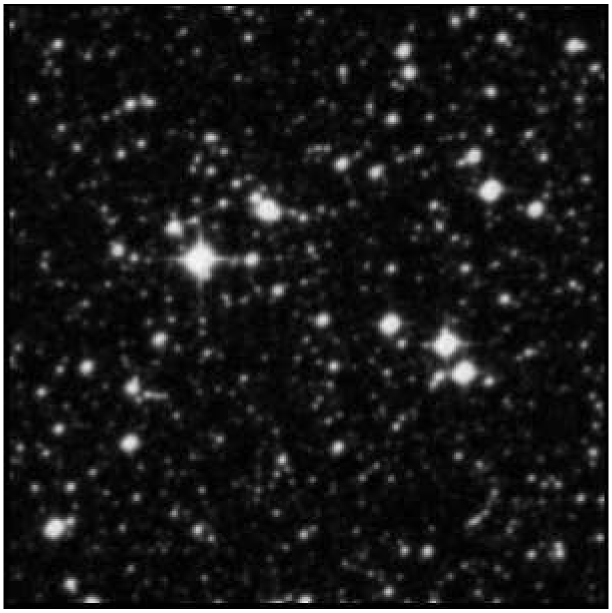
We measured the position of the outbursting object with respect to the UCAC1 reference frame and yielded R. A. = $17^{\rm h}\ 30^{\rm m}\ 45^{\rm s}.254$, Decl. = $-42^\circ\ 11'\ 42''.69$ (J2000.0) (Fig. 12). Vogt & Bateson (1982) exactly points the object at this position. On the other hand, the DSS 2 images of this region show an only faint object, implying that MM Sco was accidentally caught in a slightly brightened state in Vogt & Bateson (1982). The DSS 2 star apparently moved in the west-southwest direction between two plates (I-band, epch 1980.478 and R-band, epoch 1997.249). This star is likely the object marked on Downes' online atlas.[8] There is a possibility that MM Sco in true quiescence is fainter than the limit of the DSS 2 images and that the apparently moving object is an unrelated star. If it is the case, the outburst amplitude could exceed 6 mag. Definite quiescent identification and precise amplitude measurement should await deep direct imaging with higher spatial resolution.

4.4 MM Sco as an SU UMa-Type Dwarf Nova

Figure 13 shows the long-term visual light curve of MM Sco. Table 5 lists the observed outbursts. Six well-defined superoutbursts (JD 2450712, 2451010, 2451385, 2451729, 2452025, and 2452523) with durations longer than 8 d are unambiguously identified. The supercycle lengths are thus in the range of 298–497 d. There does not seem to be a fixed supercycle length as recorded in KK Tel (Kato et al. 2003c).

In spite of the relatively bright superoutburst magnitudes (usually 13.3–13.8), very few normal outbursts have been detected, which could have easily reached detectable magnitudes. Although the small number of observations makes it difficult to draw a firm conclusion on the type of

[8] http://icarus.stsci.edu/~downes/cvcat.



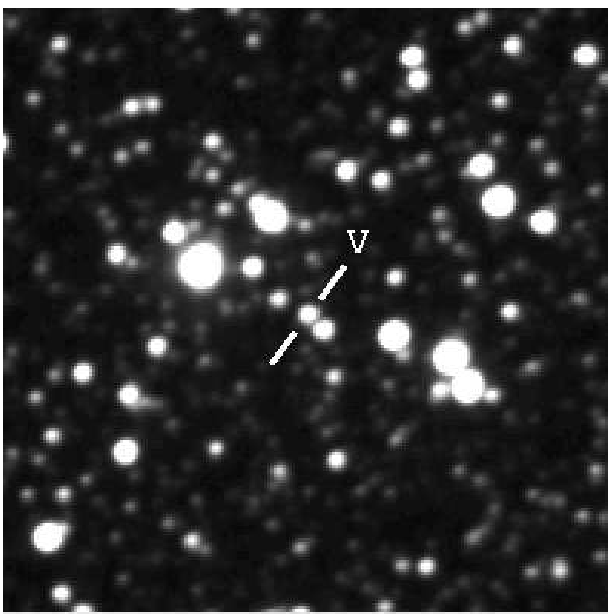


Figure 12. Identification of MM Sco. Up is north, left is east, 5 minutes square. (Upper) In quiescence, reproduced from the DSS 2 red image. (Lower) In outburst, taken on 2002 Sept. 10.77 UT by B. Monard. V = MM Sco.

outburst, the outburst on JD 2450596 was the only candidate normal outburst since 1997. Such a low number ratio normal outbursts over superoutbursts is exceptional (cf. Warner 1995; Nogami et al. 1997). In combination with the relatively short superhump period (0.06146 d), the initially proposed analogy (Petit 1956) with UV Per ($P_{\rm SH} = 0.06641$ d) looks likes to be more strengthened. The shortest intervals (28 d) of outbursts may have corresponded to a precursor outburst or a rebrightening phenomenon, both of which are relatively commonly observed in SU UMa-type dwarf novae with short superhump periods and less frequent normal outbursts (Lemm et al. 1993; Patterson et al. 1993; Howell et al. 1995b; Kato 1997; Nogami et al. 1998; Baba et al. 2000; Kato et al. 2001a; Ishioka et al. 2001).

Table 5. List of Outbursts of MM Sco.

JD start[a]	JD end[a]	Max	Duration (d)	Type
50595.9	–	13.7	–	normal?
50712.0	50724.9	13.5	>13	super
51010.9	51022.9	13.5	>13	super
51385.9	51393.9	13.8	>8	super
51729.9	51742.0	13.3	13	super
52025.0	52033.3	13.8	>8	super
52522.9	52529.9	13.4	>7	super

[a] JD−2400000.

This finding makes a contrast to what was originally suggested by F. M. Bateson (Vogt 1983). It may be either possible that the finding by F. M. Bateson did not correctly describe the outburst behavior of this object due to the lack of appropriate information at that time, or that the outburst characteristics exhibited a long-term variation. Since some SU UMa-type dwarf novae are known to show dramatic long-term variation, particularly in the number of normal outbursts (e.g. V503 Cyg: Kato et al. (2002b); DM Lyr: Nogami et al. (2003a); MN Dra = Var73 Dra: Nogami et al. (2003b)), this possibility in MM Sco needs to be carefully checked by future observations.

5 AB Nor

5.1 Introduction

AB Nor was discovered by Swope & Caldwell (1930) during the photographic survey of the southern Milky Way. Only little had been studied until very recent years. Petit (1960) simply provided a "long?" recurrence period in the table of dwarf nova candidates. Vogt & Bateson (1982) proposed a quiescent counterpart based on its blue color, but the direct attempt to identify the object by recording an outburst was not successful. The first outburst reported to VSNET was in 1997 (section 5.4); the object has been regularly monitored since then.

An outburst in 2000 April, detected by the Rod Stubbings, was most unusual. Five days after the initial brightness peak decayed, the object sudden underwent a rebrightening (vsnet-alert 4574[9]). Since such an early-stage rebrightening is usually associated with a superoutburst triggered by an immediately preceding precursor (Marino & Walker 1979; Warner 1985; Kato 1997; see also the PU CMa case in Kato et al. (2003c)) in SU UMa-type dwarf novae, AB Nor was thereby strongly suspected to be an SU UMa-type dwarf nova. Upon this alert in VSNET, W. S. G. Walker reported on the possible presence of a 0.4 mag superhump (vsnet-alert 4589[10]). Walker reported an approximate superhump period of 0.078–0.079 d, based on the second-night observation (vsnet-alert 4597[11]). Although the suggested SU UMa-type nature of AB Nor was almost confirmed by this

[9] http://www.kusastro.kyoto-u.ac.jp/vsnet/Mail/alert4000/msg00574.html.
[10] http://www.kusastro.kyoto-u.ac.jp/vsnet/Mail/alert4000/msg00589.html.
[11] http://www.kusastro.kyoto-u.ac.jp/vsnet/Mail/alert4000/msg00597.html.

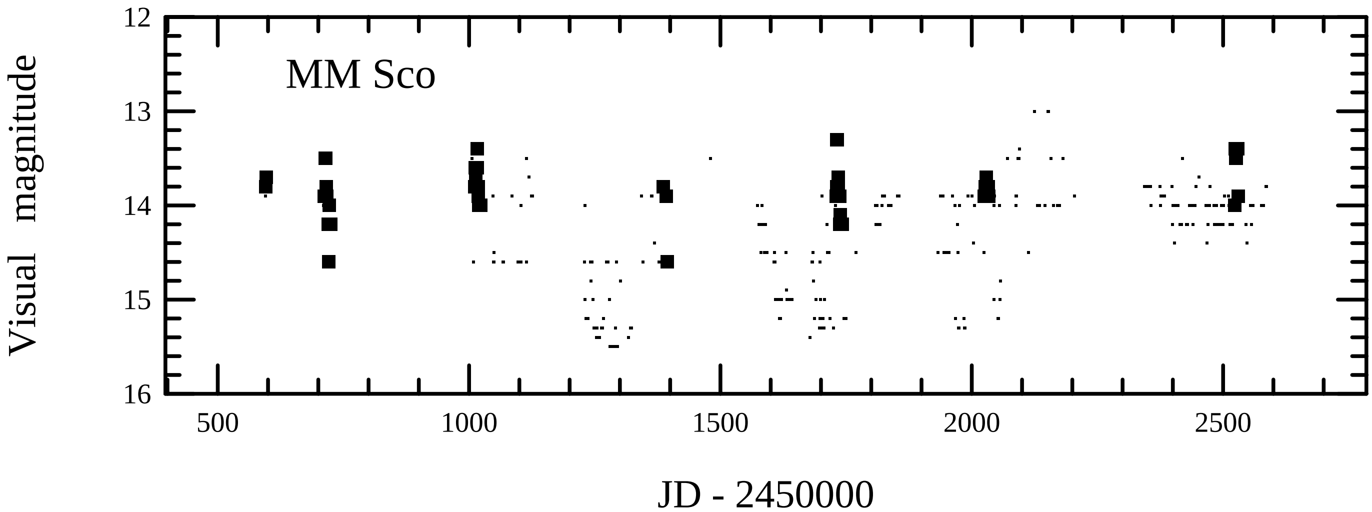


Figure 13. Long-term visual light curve of MM Sco. Large and small dot represent positive detections and upper limit observations, respectively. Outbursts other than on JD 2450596 are superoutbursts.

Table 6. Journal of the 2002 CCD photometry of AB Nor.

2002 Date		Start–End[a]	Exp(s)	N	Obs
Sept.	1	52518.901–52519.004	120	66	N
	1	52519.239–52519.366	45	173	M
	2	52520.200–52520.332	45	100	M
	4	52521.907–52522.008	120	64	N
	11	52528.887–52528.966	180	36	N
	12	52530.203–52530.343	50	159	N

[a] BJD−2400000.

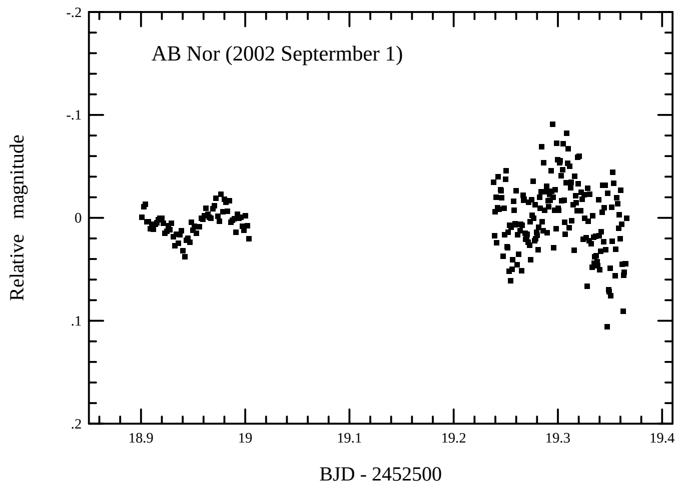


Figure 14. Light variation of AB Nor on 2003 September 1 (1 d after the detection of the outburst). The amplitudes of the superhumps were rapidly growing.

observation, the lack of long-baseline, time-resolved observation at this moment required us another opportunity for independent confirmation of superhumps, as well as precisely determining their period and evolution.

5.2 2002 August–September Outburst

The next chance arrived two years later. The 2002 August–September Outburst was detected by Rod Stubbings on August 31.437 UT at a visual magnitude of 14.0 (vsnet-alert 7457[12]). We conducted a CCD time-series photometry campaign during this outburst.

The log of observation is summarized in Table 6.

The initial observation was performed only one day later than the initial detection. The observation during this night clearly caught the evolutionary stage of the superhumps (Figure 14).

Figure 15 shows the nightly light curves of AB Nor. Unavoidable gaps are present between observations, mainly because of the wide gap in longitudinal distribution of the two observers. The superhumps had grown on September 2. The September 12 observation was performed just before the object started fading rapidly from the superoutburst plateau.

As is naturally expected from the early epoch observation coincident with the rapid evolutionary stage of the superhumps, and partly owing to the gap in observation, we have not been able to uniquely determine the superhump period common to the entire observing period. We thereby divided the data into three segments (1) early evolutionary stage: September 1, (2) fully developed stage: September 2–4, and (3) late stage: September 11–12, and first determined the superhump periods within respective segments. A period analysis of the early evolutionary stage yielded a signal around a frequency of 12.1(1) d^{-1}, corresponding to a period of 0.0829(9) d. The significance of this periodicity is 93%. This periodicity did not appear in the later segments, and it likely reflected the stage of a rapid change in the superhump period. During the latter two segments, a common frequency around 11.87(3) d^{-1}, corresponding to a period of 0.0842(3) d, was present. The selection of the alias was based on the proximity to the period derived from the segment 1 and the common presence in segment 2 (significance >99.9%) and

[12] http://www.kusastro.kyoto-u.ac.jp/vsnet/Mail/alert7000/msg00457.html

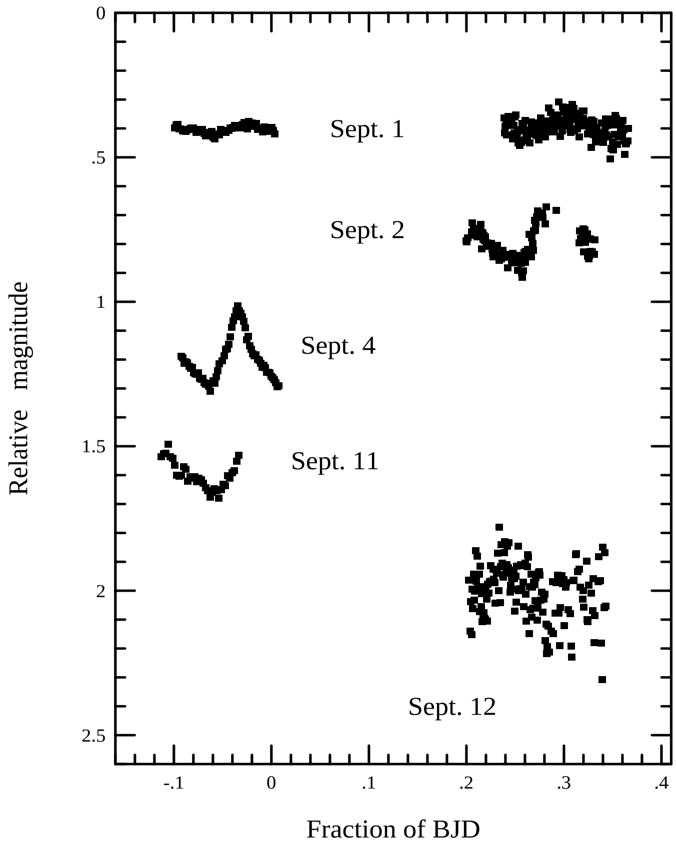


Figure 15. Nightly light curves of AB Nor. Unavoidable gaps are present between observations, mainly because of the wide gap in longitudinal distribution of the two observers.

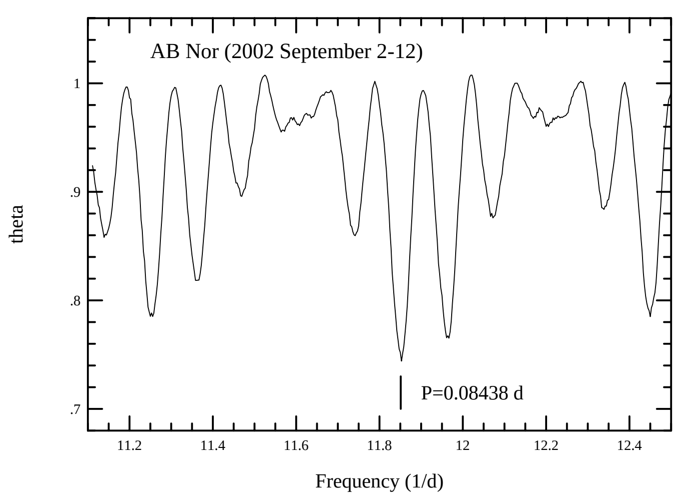


Figure 16. Period analysis of AB Nor from the September 2–12 data.

segment 3 (significance 87%). From the combination of segment 2 and 3, we obtained a period of 0.08438(2) d (Figure 16). We consider that this period is the representative superhump period of AB Nor, although a better coverage of a future superoutburst is desired to decisively identify the superhump period and its evolution.

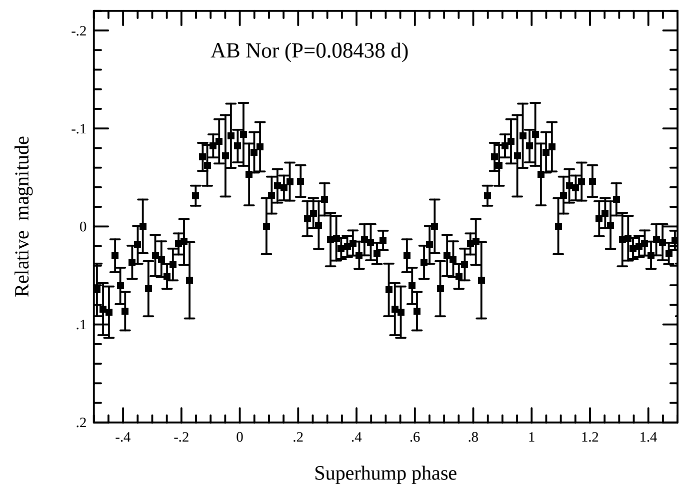


Figure 17. Mean superhump profile of AB Nor.

Table 7. List of Outbursts of AB Nor.

JD start[a]	JD end[a]	Max	Duration (d)	Type
50746.9	50747.9	13.8	> 2	super?
51320.3	51322.2	14.7	2	normal
51636.3	51649.2	14.3	13	super
52517.9	52529.9	14.0	12	super

[a] JD−2400000.

5.3 Astrometry and Quiescent Counterpart

We measured the position of AB Nor with the outburst image taken by P. Nelson on 2002 Sept. 1.438 UT. The derived position with respect to UCAC1 reference stars is R. A. = 15^{h} 49^{m} $15^{\mathrm{s}}.475$, Decl. = -43° $04'$ $48''.49$ (J2000.0), with a fitting error of about $0''.2$ for each coordinate (Fig. 18). This result is almost identical with the value derived by A. Henden using 2000 April outburst images taken by Walker (B. Sumner, vsnet-chat 2800[13]). The quiescent counterpart is clearly seen in every DSS images at mag about 20. No proper motion of this object was detected by the examination of available archived images.

5.4 AB Nor as an SU UMa-Type Dwarf Nova

Figure 19 shows the long-term visual light curve of AB Nor. Table 7 lists the observed outbursts. Two well-defined superoutbursts (JD 2451636 and 2452517) with durations longer than 12 d are unambiguously identified. The outburst on JD 2450746 is also likely a superoutburst based on its brightness. The outburst on JD 2451320 is probably a normal outburst based on its faintness. Although there are observational gaps, there seems to be little chance of many missed outbursts. The supercycle of AB Nor is thereby estimated to be $\sim$880/N d, where N is either 1 or 2. We suggest that AB Nor belongs to SU UMa-type dwarf novae with long supercycle lengths.

The derived superhump period of 0.08438 d is the one

[13] http://www.kusastro.kyoto-u.ac.jp/vsnet/Mail/chat2000/msg00800.html.

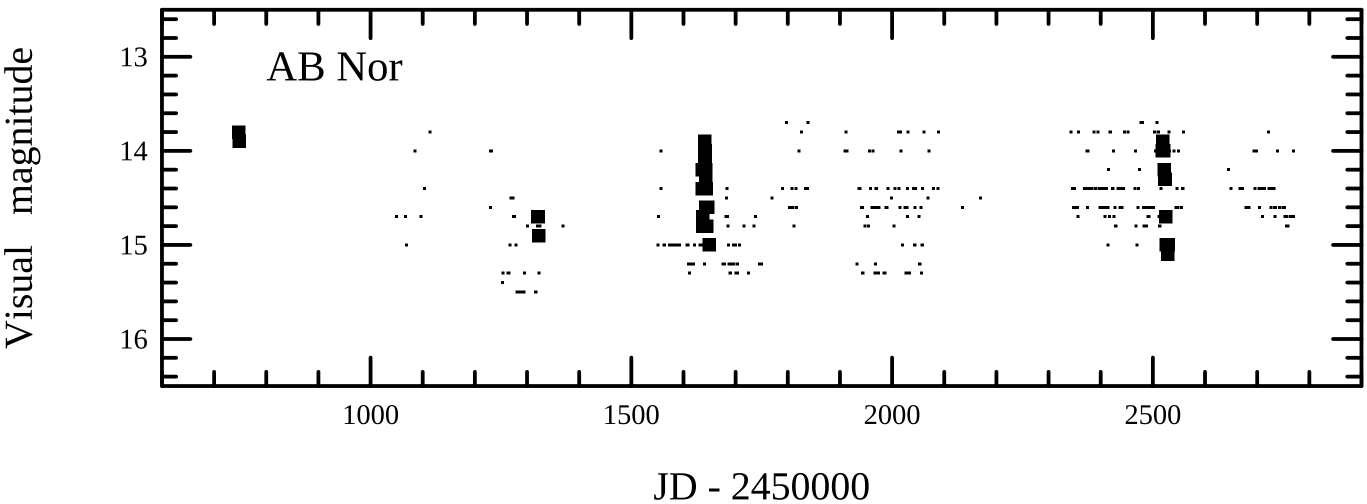


Figure 19. Long-term visual light curve of AB Nor. Large and small dot represent positive detections and upper limit observations, respectively.

of the longest periods among SU UMa-type dwarf novae below the period gap. The other long-period systems include TY PsA (P=0.08765 d: Barwig et al. 1982; Warner et al. 1989), BF Ara (P=0.08797 d: Kato et al. 2003a) and YZ Cnc (P=0.09204 d: Patterson 1979; van Paradijs et al. 1994; Kato 2001a), which show frequent outbursts and superoutbursts. Among SU UMa-type dwarf novae with similar superhump periods, EF Peg (P=0.08705 d: Kato 2002), V725 Aql (P=0.09909 d: Uemura et al. 2001) and DV UMa (P=0.08869 d: Nogami et al. 2001) have a low frequency of outbursts comparable to that of AB Nor. Both EF Peg and V725 Aql are considered to be unusual in its outburst frequency and behavior (Uemura et al. 2001; Kato 2002), and may have low mass-transfer rate comparable to WZ Sge-type dwarf novae (Kato et al. 2001b). Being easily observable at minimum (compared to EF Peg and V725 Aql), further detailed observation of AB Nor in quiescence will be helpful identifying the nature of these long-period SU UMa-type dwarf novae with supposed low mass-transfer rates.

6 CAL 86

6.1 Introduction

CAL 86 = 1RXP J054610−6835.1 = 1RXS J054613.6−683523 is a cataclysmic variable in the direction of the Large Megellanic Cloud (LMC). This star was originally selected as an *Einstein* X-ray source. Schmidtke et al. (2002) reported the detection of its short (0.066 d) orbital period and at least five outbursts from the MACHO observations. Some of the outbursts reached V = 14 (amplitude 5 mag). This orbital period, together with the presence of large-amplitude outbursts, makes CAL 86 a good SU UMa-type candidate. Upon this information we undertook a monitoring campaign (vsnet-campaign-dn 2561[14]) since 2002 December. Only one outburst was observed (in 2003 February) up to 2003 August.

Table 8. Journal of the 2003 CCD photometry of CAL 86.

2003 Date		Start–End[a]	Exp(s)	N	Obs
Feb.	24	52695.228–52695.467	45	315	M
	25	52696.038–52696.187	45	251	H

[a] BJD−2400000.

6.2 2003 February Outburst

The 2003 February outburst was detected at a visual magnitude of 13.2 on February 23.454 UT by Rod Stubbings (vsnet-alert 7645[15]). The outburst very quickly faded after the outburst detection (Figure 20). The mean fading rate of the initial 2.5 d was 1.1 mag d^{-1}, which is a typical value for a normal outburst of an SU UMa-type dwarf nova (Bailey 1975; Kato et al. 2002c).

The log of observation is summarized in Table 8.

Figure 21 shows the light curve drawn from the time-resolved CCD observations. The object was rapidly and smoothly fading during this observing period. A period analysis of the data did not reveal any superhump-type variation with an amplitude larger than 0.05 mag. Figure 22 shows an "orbital" light curve phase-averaged at the reported orbital period of 0.066 d, after removing the trend of steady decline from Figure 21. Only a marginal (0.02 mag) modulation was detected, which is not inconsistent with the general lack of orbital signatures in outbursting non-eclipsing dwarf novae (see also Kato 2001b).

6.3 Astrometry and Quiescent Counterpart

Since CAL 86 is located in the LMC field with a huge number of faint stars, we tried to make independent astrometry and identification using the outburst CCD images. The position with respect to UCAC1 frame was derived to be R. A. = $05^{\mathrm{h}}\ 46^{\mathrm{m}}\ 14^{\mathrm{s}}.973$, Decl. = $-68^\circ\ 35'\ 23''.76$ (J2000.0), with

[14] http://www.kusastro.kyoto-u.ac.jp/vsnet/Mail/campaign-dn2000/msg00561.html

[15] http://www.kusastro.kyoto-u.ac.jp/vsnet/Mail/alert7000/msg00645.html.

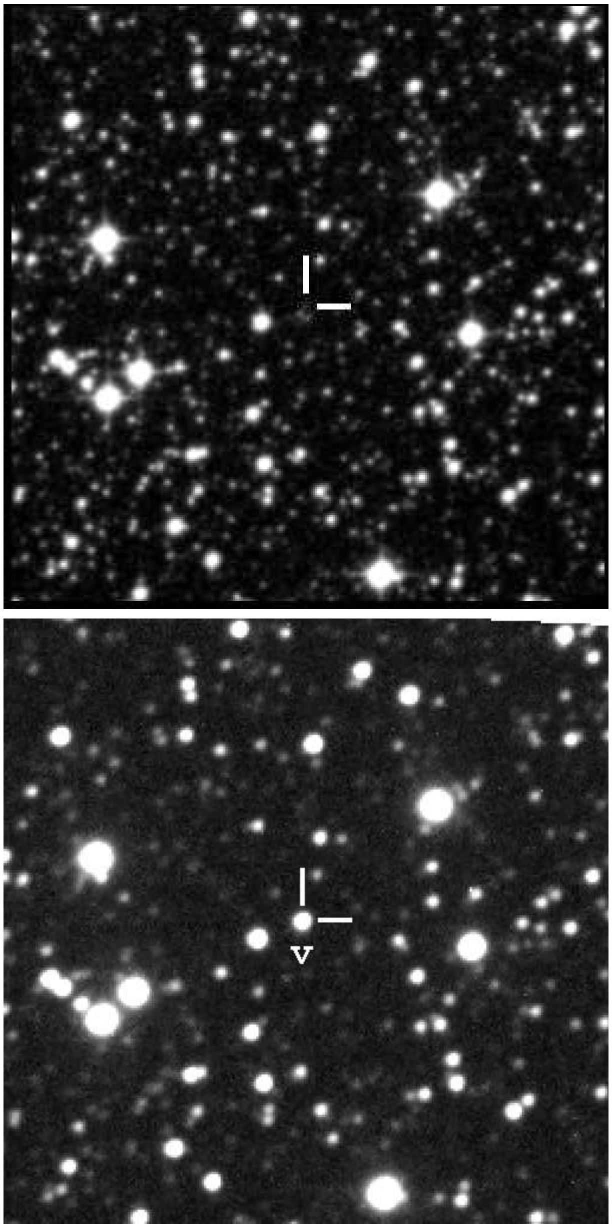


Figure 18. Identification of AB Nor. Up is north, left is east, 5 minutes square. (Upper) In quiescence, reproduced from the DSS 2 red image. (Lower) In outburst, taken on 2002 Sept. 1.438 UT by P. Nelson. V = AB Nor.

a fitting error less than $0''.1$ for each coordinate (Fig. 23). This star is identical to the one labeled as "Star No. 2" in the chart of Schmidtke et al. (1994), and to a USNO-B1.0 star having position end figures of $14^{s}.98$, $24''.1$ (r_2 mag 18.77). The examination of archived images revealed no detectable proper motion of this object, which was accidentally caught in outburst on an image taken on 1987 Jan. 24 as noted in Downes et al.'s online catalog. The USNO-B1.0 entry also shows no proper motion.

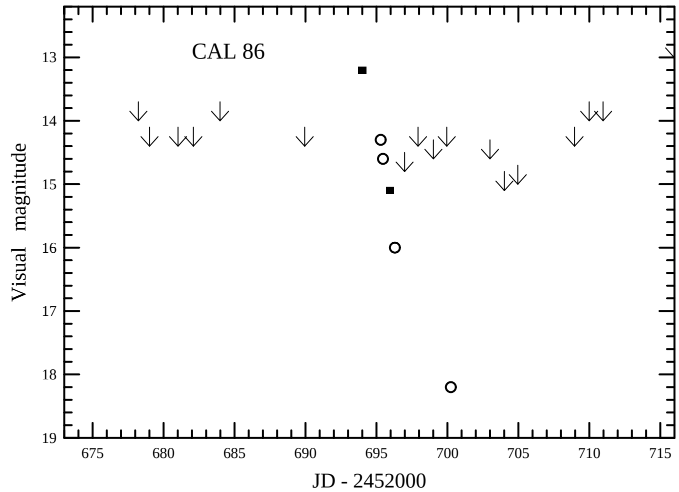


Figure 20. The 2003 February outburst of CAL 86. The filled squares and downward arrows represent positive detections and upper limit observations, respectively. The open circles represent Monard's snapshot unfiltered CCD photometry.

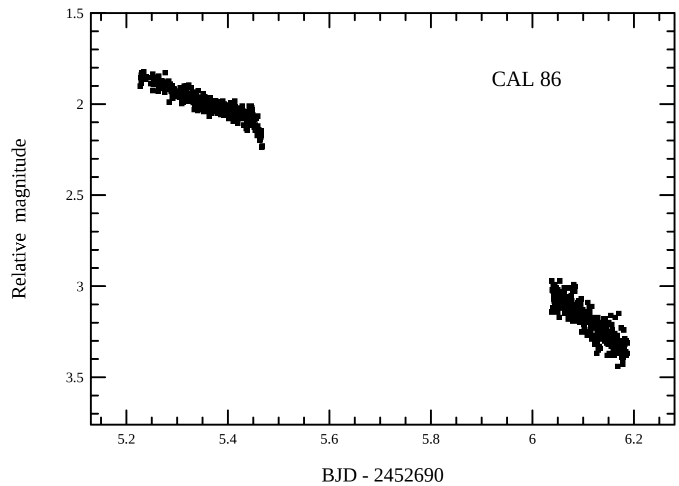


Figure 21. The 2003 February outburst of CAL 86 drawn from the time-resolved CCD observations. The magnitudes are given relative to GSC 9163.607 (approximate R_c magnitude 12.4). A rapid, smooth decline is apparent.

7 SUMMARY

We photometrically observed four southern dwarf novae in outburst (NSV 10934, MM Sco, AB Nor and CAL 86). We succeeded in measuring the superhump periods of the first three systems, and clarified the long-term outburst characteristics from long-term visual observations.

(1) NSV 10934 was confirmed to be an SU UMa-type dwarf nova with a mean superhump period of 0.07478(1) d. The star also showed transient appearance of quasi-periodic oscillations (QPOs) during the final growing stage of the superhumps. Combined with the recent theoretical interpretation and with the rather unusual rapid terminal fading of normal outbursts, NSV 10934 may be a candidate intermediate polar showing SU UMa-type properties.

(2) We determined the mean mean superhump periods of the newly identified SU UMa-type dwarf nova MM Sco to be 0.06136(4) d. The combination of a short superhump

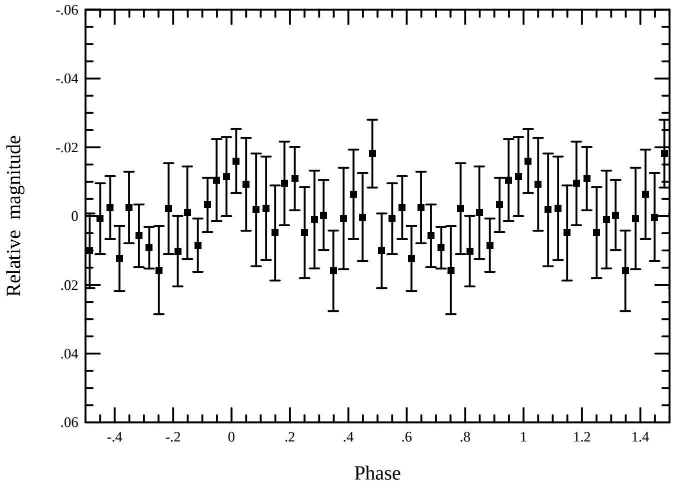


Figure 22. "Orbital" light curve phase-averaged at the reported orbital period of 0.066 d. Only a marginal (0.02 mag) modulation was detected.

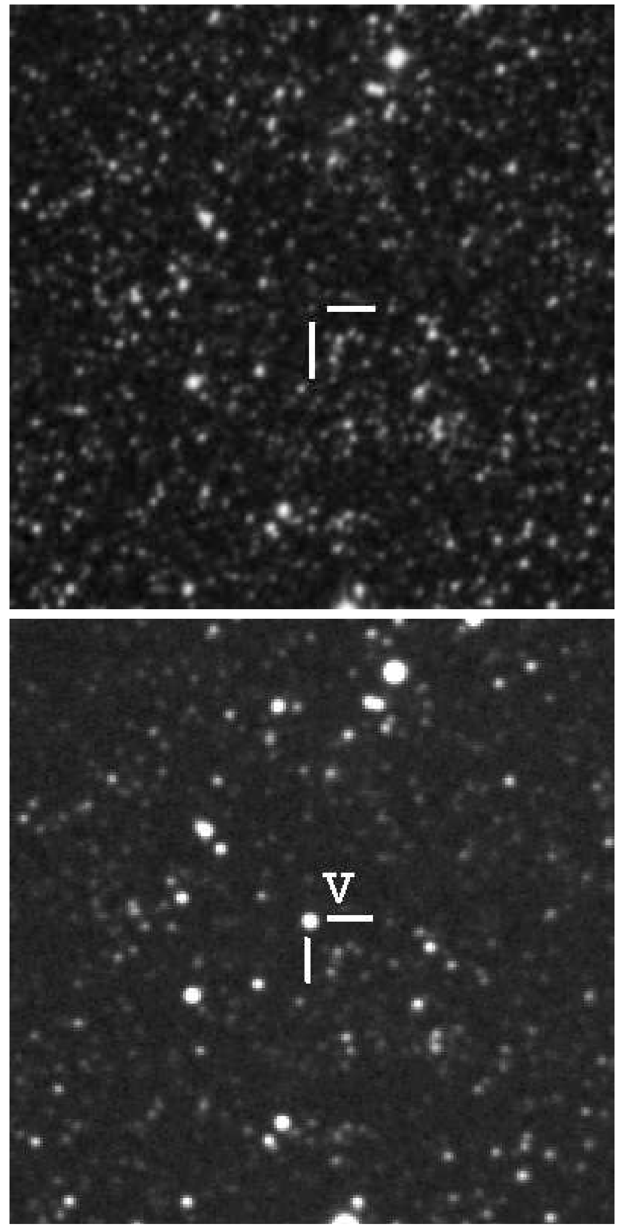


Figure 23. Identification of CAL 86. Up is north, left is east, 5 minutes square. (Upper) In quiescence, reproduced from the DSS 2 red image. (Lower) In outburst, taken on 2003 Feb. 24.79 by B. Monard. V = CAL 86.

period and a low frequency of outbursts suggests that MM Sco belongs to a class of infrequently outbursting SU UMa-type dwarf novae resembling UV Per. The true quiescence of MM Sco may be fainter than has been believed.

(3) We determined the mean superhump period of AB Nor, whose SU UMa-type nature is established by this study, to be 0.08438(2) d. We suggest that AB Nor belongs to a rather rare class of long-period SU UMa-type dwarf novae with low mass-transfer rates.

(4) We also observed an outburst of the suspected SU UMa-type dwarf nova CAL 86. We identified this outburst as a normal outburst and determined the mean decline rate of 1.1 mag d^{-1}.

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